

WAVE MOTION IN A VIBRATING STRING

LAB WAVE 1.

REFERENCES: *Physics*; Fishbane, Gasiorowicz, and Thornton
Velocity of One Dimensional Waves, Westminster College
Study of the Laws of Vibrating Strings, Westminster College

INTRODUCTION

Waves are familiar to us all--such as ocean waves, sound waves, light waves, and waves in a string. Waves may appear to be traveling or appear to be standing still. There are those being transported by a medium as for the ocean or in a guitar string and those that travel best through empty space such as the electromagnetic spectrum including visible light. Waves are a common means by which energy is transmitted in our physical world--the energy of the sun reaching and heating the earth, a clap of thunder vibrating our eardrums, or a vibration traveling down a string and back again.

For this laboratory exercise, we will focus on wave vibrations in a string under conditions that standing wave patterns are displayed. A string having a linear mass density and held under a tension is positioned between two fixed points separated by perhaps two meters. A periodic vibrating signal is set up "at" the one fixed point so that the wave signal travels along the string, is reflected at the other fixed point, and returns to its origin. With the right conditions: of distance separation, tension, string mass density, and vibration period or frequency; standing waves are observed in the string. A tuned stringed instrument, as the guitar, provides for such standing waves.

The frequency-wavelength velocity relationship is quite obvious in recognizing that the wave moves a distance of one wavelength λ in a time of one period τ or wavelength λ times number of wavelengths per unit time, which is frequency f , equals the wave velocity, $v = f\lambda$. It turns out that with the relationship $Tk^2 = \mu\omega^2$ which results for this harmonic traveling wave and that with $v = \omega/k$, we obtain $v = \sqrt{T/\mu}$. We note that the harmonic traveling wave relationship here is exactly the same as for the standing wave. From $v = f\lambda$, we see that $f = v/\lambda$ so that with $v = \sqrt{T/\mu}$ we obtain for frequency,

$$f = \frac{1}{\lambda} \sqrt{T/\mu}.$$

With a string fixed at one end and with a mechanical driver touching the string very near this one end, traveling waves are sent down the string which are reflected at the other end and return traveling back to the source. With proper adjustment of: length of vibrating string, velocity and or wavelength; the return wave will constructively add to the wave being sent by the vibrator source and produce a resonant standing wave. For these sinusoidal standing waves two vibrating segments constitute one wavelength λ , that is

one sine wave, so that with the total vibrating string length L and n the number of vibrating segments, wavelength $\lambda = 2L/n$.

PURPOSE

To determine the speed of a transverse wave in a stretched string as it depends on tension and on linear mass density and to compute the frequency based on the speed and wavelength.

MATERIALS

Function generator	Ring stand (larger)
Wave driver	2 C-clamps
2 strings	Mass hanger, masses
Pulley and mount	Meter stick
Ring stand (smaller)	Balance

PRELIMINARY QUESTIONS

1. Does the speed of a wave in a string: (a) increase or decrease with greater tension, (b) increase or decrease with greater linear mass density? Explain your reasoning.
2. Give some evidence, by example, that traveling waves transmit energy.
3. Explain that it makes sense that the velocity of a simple harmonic wave is equal to frequency times wavelength.
4. Why would one expect velocity of a wave to increase with greater frequency or greater wavelength?

PROCEDURE

Two strings are provided: string A of greater linear mass density and string B of lesser linear mass density.

1. For these strings A and B, measure the total length and the mass of each. For each compute the mass per unit length, that is, the linear mass densities, μ_A and μ_B (kg/m) and record the values in the DATA TABLE.
2. Arrange the components with the larger ring stand at one end, the wave driver close to it and clamped on the table top, and place the smaller ring stand with pulley and mount about two meters from the wave driver and clamped on the table top.

Tie string A to the rod of the larger ring stand, then resting in the vibration knob slot, and over the pulley at the other end hanging downward with the mass hanger/masses of 0.450 kg attached. The horizontal section of the string should be well leveled and the attachment to the larger ring stand, vibration knob, and pulley should be well aligned. The string should have about 2m free to vibrate. Attach the function generator electrically with two wire leads to the wave driver.

3. Measure the length, L (m), of the vibrating section of the string-- the distance between the two fixed end-point nodes. Since the string at the vibrator knob has a small vertical amplitude when vibrating, the corresponding end node is a little beyond the knob towards the tied string end-- perhaps about 2cm. Record length L_A in the DATA TABLE.
4. Turn on the function (frequency) generator with the wave driver set for a reasonably small amplitude and set on the 100 Hz frequency range. Adjust the frequency to obtain resonance, first with two vibrating segments ($n=2$). Resonance occurs when the amplitude of the transverse string motion, particularly observed at antinodes, is maximum with the vibrating segments clearly defined as a standing wave pattern with the nodes appearing fixed in space. Record this function generator resonance frequency f_n in the DATA TABLE. Continue to obtain resonance frequencies for the number of vibrating resonance segments, $n=3,4,\dots,8$ and record in the DATA TABLE. For higher n , if necessary switch wave driver frequency to a higher range.
5. Still for the greater mass density string (string A, white) and now for resonances corresponding to $n=2$ and $n=4$; proceed to obtain resonance frequency data for five tensions with hanging masses of: 0.200kg, 0.300 kg, 0.400 kg, 0.500kg, and 0.600kg and record in the DATA TABLE. The interest here is to study the wave velocity in the string as affected by tension.
6. For a different linear mass density string, replace string A with string B now with a hanging mass of 0.300 kg. As for PROCEDURE Step 3 above, measure the length L_B of the vibrating section of string B and record in the DATA TABLE. Proceed as in procedure step 4 above starting with $n=2$ to obtain resonance frequencies for $n=2,3,\dots,6$ and record in the DATA TABLE. In the same manner for $n=4$ obtain and record the resonant frequencies. The frequency setting of the function generator will likely require being set to the next higher frequency scale as resonance frequencies become greater than 100 Hz.

DATA TABLES

Linear mass density: $\mu_A =$	kg/m	Vibrating string length: $L_A =$	m	Hanging mass: 0.450kg; 0.300 kg
Linear mass density: $\mu_B =$	kg/m	Vibrating string length: $L_B =$	m	Tension, $T = mg$: 4.41N; 2.94N

I. Frequencies and Velocities- Experimental and Theoretical

String	Number of segments n	Frequency f_n Hz (vibrator)	Wavelength $\lambda_n = 2L/n$ m (measured)	Velocity $v_n = f_n \lambda_n$ m/s (measured)	Velocity $v_n = \sqrt{T/\mu}$ m/s (calculated)	Frequency $f_n = 1/\lambda_n \sqrt{T/\mu}$ Hz (calculated)	$\frac{f_{n,vib}}{f_{n,cal}}$	$\frac{v_{n,meas}}{v_{n,cal}}$
A	2							
A	3							
A	4							
A	5							
A	6							
A	7							
A	8							
B	2							
B	3							
B	4							
B	5							
B	6							

II. Variation of Velocity with Tension

Number of segments n	Hanging mass kg	Tension, T $T = mg$ N	Frequency f_n Hz (vibrator)	Wavelength $\lambda_n = 2L/n$ m (measured)	Velocity $v_n = f_n \lambda_n$ m/s (measured)	Velocity $v_n = \sqrt{T/\mu}$ m/s (calculated)	$\frac{v_{n,meas}}{v_{n,calc}}$
2	0.200	1.96					
4	0.200	1.96					
2	0.300	2.94					
4	0.300	2.94					
2	0.400	3.92					
4	0.400	3.92					
2	0.500	4.90					
4	0.500	4.90					
2	0.600	5.88					
4	0.600	5.88					

ANALYSIS

1. For DATA TABLE I and for string A and string B and corresponding linear mass densities, vibrating string lengths, and tensions as entered in the DATA TABLE; compute and record in the DATA TABLE columns provided: wavelength $\lambda_{n,meas}$, velocity $v_{n,meas}$, and $v_{n,calc}$, and frequency $f_{n,cal}$.
2. For the last two columns of the DATA TABLE compute the frequency ratios and the velocity ratios as indicated. Discuss and evaluate these ratios and attempt to account for how well the values correspond to expectations.
3. Discuss explain the correspondence of frequency with wavelength in relation to number of vibrating segments n .
4. Discuss frequencies and velocities for string A and string B for each and in relation to each other with respect to their different linear mass density μ and tension T .
5. For DATA TABLE II with string A, the linear mass density and vibrating string length given in the DATA TABLE as noted in ANALYSIS step 1 above and the tensions already entered into DATA TABLE II, compute and record in the DATA TABLE columns provided: wavelength $\lambda_{n,meas}$, velocity $v_{n,meas}$, and velocity $v_{n,calc}$, and then for the last column the velocity ratio. Discuss the dependence of velocity of the wave in the string on the tension for both the $n=2$ and $n=4$ cases. Discuss the velocity ratios.